Effects of Sample Preconditioning on Asphalt Pavement Analyzer Wet Rut Depths

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Moisture damage of asphalt mixes, better known as stripping, is a major distress affecting pavement performance. AASHTO T283 has historically been used to detect moisture susceptible pavements through the determination of a tensile strength ratio (TSR). Results from AASHTO T283 have been inconsistent. As a result there has been increased interest in finding an alternative test. Preliminary indications reveal that loaded wheel rut testers, such as the Asphalt Pavement Analyzer (APA) have the potential to detect moisture susceptible mixtures. To date, no standard test methodolgy has been developed. The objective of this study was to evaluate the effects of sample preconditioning on APA rut depths. Eight different mixes from seven project sites were evaluated with the APA. Samples were tested using four different preconditioning procedures: dry, soaked, saturated, and saturated with a freeze cycle. The results were compared with TSR values as well as other aggregate tests. The results indicate that the APA can be utilized to evaluate the moisture susceptibility of asphalt mixes. Additionally, the results indicate that harsher preconditioning of saturation and saturation with a freeze cycle did not result in increased wet rut depths. Using only dry and soaked conditioning appears to be adequate.

INTRODUCTION

When the adhesive bond between asphalt and aggregates is loosened or weakened by the action of moisture, we say that stripping has occurred. The damaging effects that can result include rutting and cracking due to shear forces. Although the phenomenon of stripping has been acknowledged for over 50 years, being able to predict the moisture susceptibility of aggregates has not been adequately solved. Part of the attention of the Strategic Highway Research Program (SHRP) was focused on determining a test method to evaluate the moisture damage potential of aggregates. This research was not completely successful. The recommendations from SHRP were to continue using AASHTO T283, "Resistance of Compacted Bituminous Mixture to Moisture Induced Damage." Besides the occasional inability of AASHTO T283 to accurately determine moisture susceptibility, the test is also time intensive (three to four days to complete). Thus, a test method that would accurately predict stripping potential and take hours rather than days to complete would be attractive to highway agencies and contractors alike.

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Research by the Colorado DOT (*1*) and the Georgia DOT (*2*) has shown that loaded wheel testing devices can be used to identify moisture sensitive mixes. Because rutting is one of the symptoms of stripping, developing a test method with these devices is very logical. Additionally, the loaded wheel device used in this study, the Asphalt Pavement Analyzer (APA), has the ability to test samples while they are submerged in water providing a more direct simulation of water-asphalt interaction.

The objective of this study was to evaluate the effects of sample preconditioning on APA rut depths. The tensile strength ratios (TSR), methylene blue values, and sand equivalents of the samples were also evaluated and compared with APA rut depths. Additionally, the viability of using of the APA in predicting moisture susceptible mixes was evaluated.

THE EXPERIMENT

Materials

Eight different mixes from seven project sites in Kansas were used. The initial intent was to have at least two mixes in each of the "good," "fair," and "poor" TSR categories without any anti-stripping agent being applied. In other words, a couple of the mixes should easily pass T 283 (good, TSR > 90), a couple of the mixes should have TSRs in the 75 to 85 range (fair), and a couple of the mixes should have TSRs less than 70 (poor). However, in the end, two mixes had TSRs in the 90s, four mixes that had TSRs between 75 and 85, and two mixes that had TSRs between 70 and 75.

Aggregates and asphalt cement were obtained from each project and samples were compacted at the optimum asphalt content to 7% ± 0.5% VTM using the Superpave Gyratory Compactor (SGC). The asphalt cement was either a PG 58-22 or a PG 58-28. Seven of the eight mixes were surface mixes and one was a binder mix. Two mixes were Superpave mixes (mix designation S). The Kansas Department of Transportation (KDOT) made all of the samples, except for those used at Site 7. The University of Kansas made Site 7 samples. Table 1 shows a summary of the material characteristics and mix designation of the eight mixes.

Asphalt Pavement Analyzer (APA)

The APA holds six SGC compacted cylindrical samples (approximately 150 mm x 75 mm) for testing simultaneously. The air and water bath temperatures of the APA can be controlled. Air

TABLE 1 Material Characteristics of Samples by Site

Location	Mix Designation	PG Grade	VTM	TSR	Methylene Blue	Sand Equivalent
Site 1	SM-1T	58-22	7.0	82.5	5.5	78.0
Site 2	BM-2A	58-28	6.7	73.5	14.0	79.5
Site 3	BM-2	58-22	6.8	84.5	6.5	69.5
Site 4	BM-2A	58-28	6.7	98.2	29.0	77.0
Site 5	SM-2C	58-28	7.4	92.5	19.5	77.5
Site 6A	BM-1	58-22	6.6	83.1	8.0	68.0
Site 6B	BM-1	58-22	6.7	77.2	10.0	61.5
Site 7	BM-1	58-22	7.0	74.8	*	76.0

*Values not available.

temperatures and water bath temperatures of 40°C were used. Rutting is attained by cycling 0.44 kN (100 lb.) loaded wheels on rubber hoses that have air pressures of 690 kPa (100 psi). After an initial zero-reading is made, the APA can be set to cycle as many times as desired. For this study rut depth measurements were obtained at 500, 1,000, 2,000, 4,000, and 8,000 cycles.

Test Plan

Preconditioning

Generally, two samples from each project site and at each condition state were tested in the APA. Four preconditioning states were tested. The first preconditioning state was accomplished by placing the samples in the APA at a chamber temperature of 40°C for four hours prior to running the APA. This condition state is referred to as *40°C dry*. The second preconditioning state was accomplished by soaking the samples in a 40°C water bath for 2 hours prior to running the APA. In this condition state, the samples were tested in the APA while submerged in 40°C water. This condition state is referred to as *40°C soak*. In the third preconditioning state, the samples were vacuum saturated in accordance with AASHTO T283 and then placed in a 60°C water bath for 24 hours (*3*). Next, the samples were placed in the APA's water bath at 40°C for two hours and then tested in the APA while submerged in 40°C water. This condition state is referred to as *40°C saturated*. In the fourth preconditioning state, the samples were treated the same as the third state, using the optional freeze cycle of AASHTO T283. As in the previous two condition states, the samples were placed in the APA's water bath for 2 hours at a temperature of 40°C and then tested submerged in the APA in 40°C water. This condition state is referred to as *40° C freeze*.

TSR, Methylene Blue, and Sand Equivalent Testing

The KDOT provided TSR values, methylene blue values, and sand equivalents. Methylene blue values were not available for Site 7. The results are shown in Table 1.

Data Analysis

After testing in the APA, the rutting data at 8000 cycles was analyzed using a two-way analysis of variance (ANOVA) in which rut depth was the response variable (or Y variable) and project site and condition state were the two effects (or X variables). Additionally, the Tukey-Kramer method was used to determine where there was a statistically significant difference between the means of the response variables. Finally, comparisons of TSR values, methylene blue values, sand equivalents, rut depths, and rut ratios were completed. Rut ratio is defined by the following equation:

$$\text{Rut ratio} = \frac{\text{Rut Depth at Condition State X}}{\text{Rut Depth at } 40^{o}\text{C Dry}} \quad (1)$$

RESULTS

Analysis of Variance (ANOVA)

A two-way ANOVA was performed using the four condition states, and the results are shown in Table 2. The results clearly show that the rut depth variation was due to the effects of the whole model as opposed to chance. The F ratio for the whole model was 25.42 and the probability of a greater F value occurring if the variation of the rut depth resulted from chance alone was less than 0.0001 (Prob.>F). The results also show that project site alone, condition state alone, and project site - condition state interaction all had significant effects upon the variation of the rut depth.

TABLE 2 Analysis of Variance Results

Source	Degrees Freedom	Sum Squares	Mean Square	F Ratio	Prob. >F
Site	7	160.58	22.94	74.0	0.0001
Conditioning	3	30.90	10.30	33.2	0.0001
Site * Cond.	21	55.13	2.62	8.4	0.0001
Error	30	9.39	0.31		
Total	61	256.00			

A statistical comparison using the Tukey-Kramer test was completed on the means of the main effects of site and condition state. The Tukey-Kramer test compares the actual difference between group means with the difference that would be significantly different (*4*). The difference needed for statistical significance is called the least significant difference (LSD). The results of this comparison test on the sites are shown in Table 3. The results indicate that the majority of the sites had significantly different rut depths.

TABLE 3 Comparison of Group Means for Site, Tukey-Kramer Test

Grouping*	Mean Rut Depth (mm)	Site
A	7.95	Site 2
B	5.93	Site 1
C	5.17	Site 6B
C & D	4.83	Site 4
D & E	4.36	Site 7
E	4.08	Site 5
F	2.83	Site 3
F	2.44	Site 6A

* Means with the same letter not significantly different.

The results of the Tukey-Kramer test on the preconditioning states indicated that the means of the *40°C dry, 40°C saturated*, and *40°C freeze* condition states were not significantly different. This result was somewhat unexpected. It means that the AASHTO T283 preconditioning had little effect upon the rutting results. As shown in Table 4, the *40°C soak* preconditioning had the greatest rut depth followed by the *40°C saturated*, followed the *40°C dry*, followed by the *40°C freeze*, which had the least amount of rutting. A one-way ANOVA completed on each of the eight sites indicated that the probability of a greater F value (Prob.>F) occurring by chance alone was less than 0.05 for each site. Thus, the effect variable, conditioning, was a significant factor in the variability of the rut depth data.

TABLE 4 Comparison of Group Means for Sample Conditioning, Tukey-Kramer Test

Grouping*	Mean Rut Depth (mm)	Sample Conditioning
A	5.88	*40°C Soak*
B	4.29	*40°C Saturated*
B	4.23	*40°C Dry*
B	4.09	*40°C Freeze*

* Means with the same letter not significantly different.

Correlation Analysis

As discussed previously, the TSR value generated by AASHTO T283 is the current accepted measure for moisture susceptibility. However, in Europe there are several other aggregate tests that are used in the evaluation of aggregates including the methylene blue and sand equivalent tests (*1*). Therefore, these two tests were included in the analysis to determine if any correlation exists. The comparison includes the rut depths at 8000 cycles with *40°C dry* and *40°C soak* conditioning and the rut ratio of the *40°C soak* rut depths to *40°C dry* rut depths as defined by equation 1. The correlation coefficients between the pairs were poor, generally less than 0.5. The best correlation was between TSR and the methylene blue test (r=0.70)

Threshold Value

Table 5 ranks the eight sites from best to worst in each of the test categories. The site number is provided first followed by the test parameter in parenthesis. There is little consistency in ranking between the test results. The TSR and methylene blue test results were fairly consistent, and the rut depth results at *40°C dry* and *40°C soak* were also fairly consistent. However, the rankings from the sand equivalent results and the rut ratio results do not appear to correlate with any of the other categories.

As shown in Table 5, the APA was not able to identify all the sites with TSR values below 80%, the usual specification criteria. However, AASHTO T283 is not infallible either. All sites with TSR values less than 80% had soaked rut depths greater than 5.00 mm. Two sites with TSR values above 80%, Sites 1 and 4, had soaked rut depths greater than 5.00 mm as well. Site 4 (TSR = 98.2%) is unstable with a dry rut depth of 5.93 mm and should not be used. Site 1 had a TSR of 82% but a wet rut depth of 10.6 mm and a rut depth ratio of 1.7, indicating moisture damage potential. A threshold value of 5.00 mm for *40°C soaked* preconditioning differentiated between mixes with low TSR's (< 80%) and mix instability from those with satisfactory TSRs, greater than 80%.

CONCLUSIONS

1. The effect of the AASHTO T283 sample conditioning on rut depths did not yield significant differences. It appears that the conditioning by saturation and the optional freeze cycle of AASHTO T283 are not necessary to evaluate moisture susceptibility of asphalt mixes by APA rut depths. As was indicated earlier, the saturated conditioning was performed in accordance with AASHTO T283, and this resulted in saturation levels of 60% to 70%, higher than that measured in the soaked samples. It is possible that the higher saturation levels resulted in excess pore water pressure being developed during the cyclic loading. This excess pore water pressure could help support the load resulting in reduced rut depths when compared to the soaked samples.
2. The APA rut depths of the *40°C soak* conditioning were significantly greater than the other conditioned rut depths. With additional refinement, a method to utilize the APA in evaluation of moisture susceptibility of asphalt mixes could be developed. Preliminary results indicate that a threshold value of 5.00 mm for *40°C soak* rut depths would be appropriate.
3. The sand equivalent and rut ratio results do not correlate well with the TSR values. However, the methylene blue values do have a fairly good correlation with the TSR values.

TABLE 5 Comparison/Ranking of Test Results by Site*

TSR	Methylene Blue	Sand Equivalent	40°C Dry Rut Depth	40°C Soak Rut Depth	Rut Depth Ratio
4 (98.2)	4 (29.0)	2 (79.5)	6A (1.83)	3 (3.08)	3 (0.95)
5 (92.5)	5 (19.5)	1 (78.0)	3 (3.25)	6A (3.60)	6B (0.99)
3 (84.5)	2 (14.5)	5 (77.5)	5 (4.73)	5 (4.73)	4 (1.01)
6A (83.1)	6B (10.0)	4 (77.0)	1 (3.88)	7 (5.00)	7 (1.08)
1 (82.5)	6A (8.0)	7 (76.0)	7 (4.63)	6B (5.53)	5 (1.35)
6B (77.2)	3 (6.5)	3 (69.5)	6B (5.58)	4 (6.00)	2 (1.36)
7 (74.7)	1 (5.5)	6A (68.0)	4 (5.93)	2 (8.50)	6A (1.97)
2 (73.5)	N/A	6B (61.5)	2 (6.25)	1 (10.60)	1 (1.70)

* Site # followed by test parameter in parenthesis.
N/A = Data not available.

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